Propagation of epileptic spikes revealed by diffusion-based constrained MEG source reconstruction

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INTRODUCTION and HYPOTHESIS

Magnetoencephalography (MEG) source reconstruction is becoming recognized as a useful technique to non-invasively localize epileptic foci. Giving a direct access to the temporal succession of cognitive processes, this modality should allow to follow on source space the propagation of spikes.

The inverse problem being sensitive to the functional noise of MEG recordings, the recovery of dipoles magnitude is usually performed on averaged trials. But, the averaging of epileptic spikes is difficult due to their different types and especially different times of propagation [3]. Thus, studies which average epileptic spikes at the maximum of their intensity can not explore the propagation characterizing each epileptic spike. Furthermore, the MEG inverse problem on a distributed source model allows to follow the propagation of the spike at the surface of the cortex, but is highy undetermined and needs regularization.

Cortex parcellation as a regularization term is appropriate for the reconstruction of a single spike. First, constraining sources, in areas with similar structural connectivity, to have the same dipole magnitude, it gives a focal reconstruction and is very robust to functional noise. Thus, the MEG inverse problem can be applied to a single spike. Secondly, the reduction of dimensionality of the source space allows to extract compact information about the spatial and temporal propagation of the spike.

Diffusion MRI is the only in-vivo and non invasive imaging modality giving access to the structural connectivity profile of cortical sources [1]. Sources which share a close connectivity profile have a close functional contribution to the overall system [2]. Therefore, diffusion-based cortex parcellation is a suitable regularisation to constrain the reconstruction of sources to be equal in properly defined areas. Thus, we propose a method to perform cortex parcellation via diffusion data and reconstruct the cortical activity of an epileptic spike, without averaging, by constraining the activity of sources to be equal in areas sharing a similar structural connectivity.

This abstract presents a methodology to study the propagation of epileptic spikes. In general, the maximum of activity does not happen at the beginning of a spike. However, the source localization plot is normalized by the maximal activity. Thus, it is very difficult to interpet results when the activity is much less important than this maximum, the dynamic of the reconstruction in a time window much although with less energy may be significative. That is why, we propose a method to study the time-dependant activity of the diffusion-based areas and identify the areas at the origin of the activity.

METHODOLOGY

Preprocessing and Cortex parcellation

Fist, we apply the preprocessing illustrated in Fig.1-a). Then, we perform the diffusion-based cortex parcellation described Fig.1-b) and published in [4]. Thus, sources are clustered into areas sharing a close structural connectivity.

The MEG inverse problem with a parcellated source space

We reduce the inital distributed source space $\mathbf{S}$ into $\mathbf{s}$ in accordance with the cortex parcellation:

$$\mathbf{S} = \mathbf{P} \times \mathbf{s} \text{ with } \mathbf{P}(i,j) = \begin{cases} 1, if \text{ source i is in area j} \\ 0, if not \end{cases}$$

and compute the MEG forward problem $\mathbf{G_P}$ for the parcellated source space $\mathbf{s}$: $\mathbf{G_P} = \mathbf{G} \times \mathbf{P}$

Thus, the MEG inverse problem on the parcellated source space using Tikhonov regularization becomes :

$$min_{\mathbf{s}} \mid\mid \mathbf{M} - \mathbf{G_p s} \mid\mid^2 + \lambda \mid\mid \mathbf{s} \mid\mid^2$$

where $\mathbf{M}$ contains the MEG measurements.

Study of the propagation of an epileptic spike

At each time sample, we want to determine the cortical areas at the origin of the activity. We call $\mathscr{S}_t$ the set of these areas, for a time sample t.

For each time sample t, we compute the power $\mathscr{P}_{p,t}$ of each area p on a sliding time window $[t-\alpha, t+\alpha]$:

$\mathscr{P}_{p,t} = \sum_{i=t-\alpha}^{t+\alpha} \mid \mathbf{s}(p,i) \mid^2$.

$\mathscr{S}_t = \{p_a : \mathscr{P}_{p_a,t} > F * max(\mathscr{P}_{p,t}), \forall p\}$ with F a pourcentage.

Fig.2 presents the reconstruction of each area in $\mathscr{S} = \cup_{t=min(t)}^{max(t)} \mathscr{S}_t$. For each time sample, we are able to select cortical areas at the origin of the activity.

Then, we can extract time windows w where for each time sample t_w in w, $\mathscr{S}_{t_w}$ remains the same. Visualizing these sets of areas on the cortical mesh, we are able to study the spatial propagation of the spike knowing the regions that are consecutively involved in the spike activity, see Fig.2-B. Furthermore, we can define the series of activated patches for each time window w, see Fig.4.

RESULTS

We perform the proposed methodology with the diffusion data, the anatomical MRI and the MEG recording of an epileptic subject. The cortex parcellation, composed of 602 areas, is presented in Fig 1 and the source reconstruction of a spike with $F = 70\%$ is presented in Fig.2 and Fig.3. The study of the spatial propagation of the spike is presented in Fig 3.

CONCLUSION

We have proposed an efficient pipeline to study the spatial propagation of an epileptic spike. Diffusion-based cortex parcellation constrains sources with similar structural connectivity to have the same dipole magnitude and facilitates the interpretation of MEG data at source level. The methodology is applied on MEG recordings but can easily be extended to EEG recordings. The different results provides clinicians with tools to understand which the cortical region is at the origin of each epileptic spike, where is its propagation and its duration. Clarifying the localisation into diffusion-based cortical regions, we are able to evaluate the difference between each one of the epileptic spikes. Furthermore, the analysis of the correlation of the signal in an area along the time and of the connectivity degrees between areas will improve the understanding of the propagation of epileptic spikes.

References

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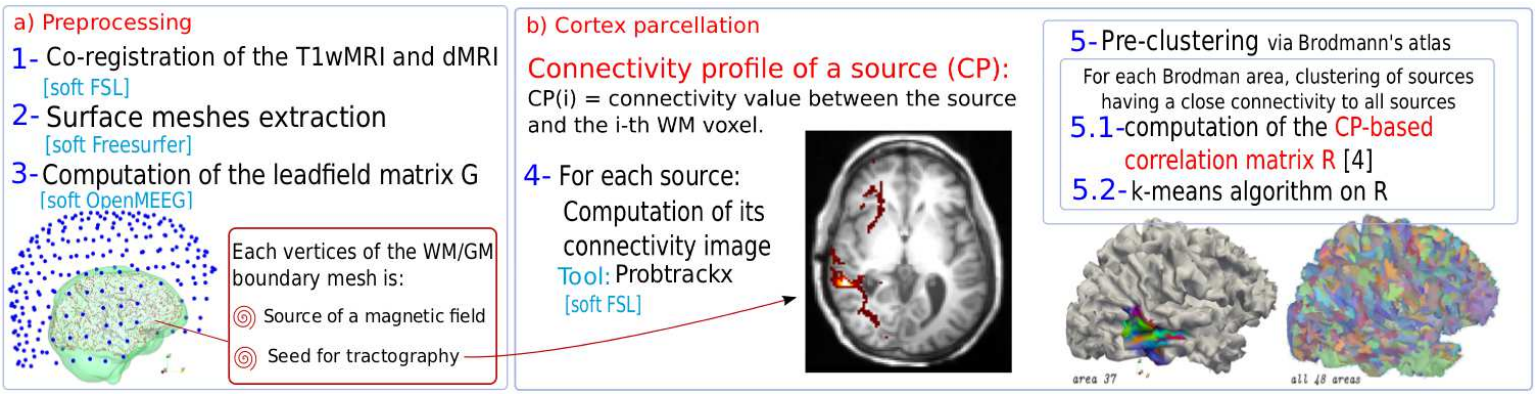

Figure 1: Steps for the preprocessing (a) and the cortex parcellation (b). Step 1- Co-registration between the anatomical MRI (T1wMRI) and the diffusion MRI (dMRI). Step 2, we extract surfaces meshes from the T1wMRI and compute, Step 3, the MEG forward problem G such as G(i,j) is the magnetic field generated by the j-th source on the i-th sensor. To parcellate the cortex, we compute the connectivity profile of each cortical source, step 4, with a probabilistic tractography algorithm. Step 5, to reduce the dimension of the source space, we cluster via diffusion data inside each one of the Brodmann's area: we compute the correlation matrix between the CP of the sources and cluster it via a K-means algorithm [5].

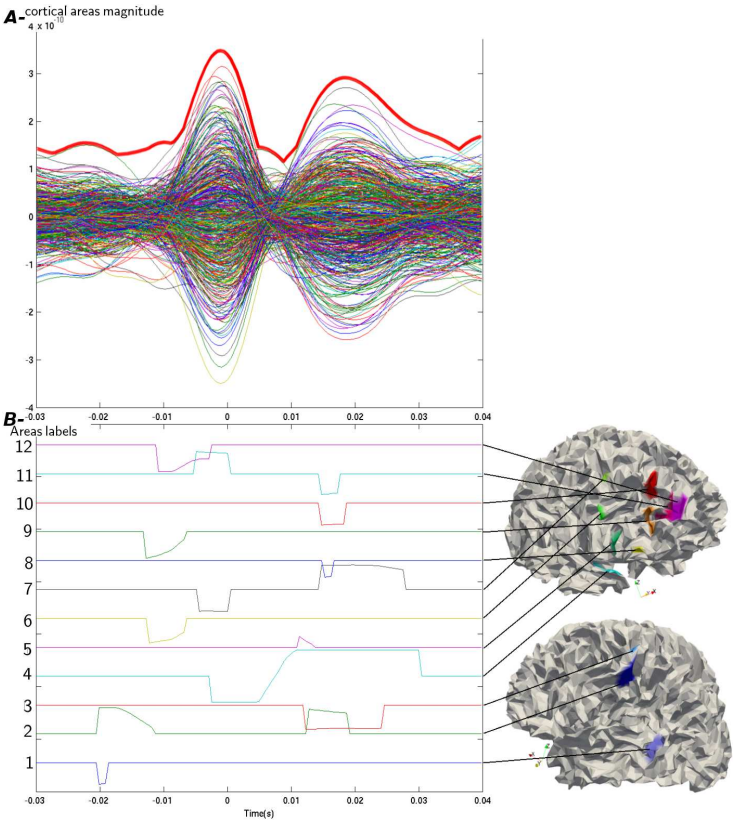

Figure 2: **Graph A-** Reconstruction of the 602 diffusion-based areas. The bold red line corresponds to the maximum of activity at each time sample. **Graph B-** Reconstruction of the 12 areas a of $\mathscr{S}$. At a time sample t, the reconstruction of the area a_i, $i \in [1, 12]$, is different of 0 if $a_i \in \mathscr{S}_t$. The black arrows match the areas labels and their localisations on the cortical mesh.

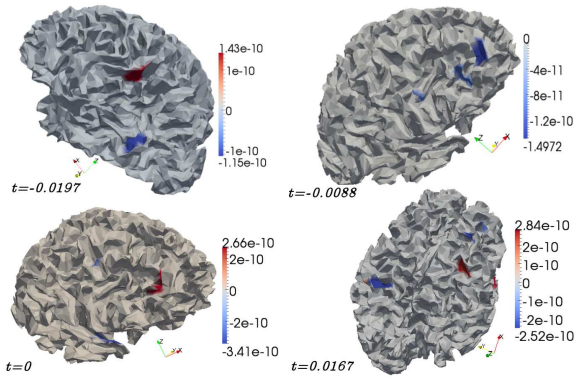

Figure 3: Reconstruction of the activity of areas of $\mathscr{S}_{t_i}$ for 4 time samples $t_i, i \in [1:4]$.

Areas labels							Time windows	
							-0.29983	-0.2644
1	2						-0.2644	-0.19169
2							-0.19169	-0.13271
2	9						-0.13271	-0.12779
2	6	9					-0.12779	-0.11796
6	9						-0.11796	-0.1135
6	9	12					-0.1135	-0.68813
12							-0.68813	-0.5467
11	12						-0.5467	-0.49152
7	11	12					-0.49152	-0.29491
4	7	11					-0.29491	0
4							0	0.1813
4	5						0.1813	0.11796
3	4	5					0.11796	0.12288
2	3	4	5				0.12288	0.13271
2	3	4					0.13271	0.14254
2	3	4	7	1	11		0.14254	0.14746
2	3	4	7	8	1	11	0.14746	0.1622
2	3	4	7	1	11		0.1622	0.1723
2	3	4	7	1			0.1723	0.18186
2	3	4	7				0.18186	0.18678
3	4	7					0.18678	0.2484
4	7						0.2484	0.27525
4							0.27525	0.29983

Figure 4: The 24 time windows w, within which $\mathscr{S}_t$ remains the same.